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AN OPERATIONS RESEARCH APPROACH TO DOUGLAS-FIR THINNING

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ABSTRACT

Forest managers are faced with increasingly complex situations which often render existing planning procedures inadequate. Operations research techniques such as mathematical programing are being explored as possible aids. In this study, a mathematical programing technique is used as the basis for a systematic framework for planning commercial thinning operations. This systematic approach, termed "the unit approach" because thinning opportunities are defined as harvesting units, is demonstrated, tested, and compared with existing planning methods which are characterized by the term "rules of thumb."

The systematic approach utilizes information from a Bureau of Land Management special study area of 50,000 acres in western Oregon. The results show that the systematic approach provides managers with an improved framework for documenting information, optimizing thinning programs, and testing the consequences of different planning strategies and situations. Although the systematic approach did not yield dramatic dollar gains in this study, the potential for obtaining sizable benefits exists, particularly in larger, more complex planning situations. The major obstacles to implementing the unit approach seem to be finding or training qualified people and the costs of establishing the system.

KEYWORDS: Thinning (trees), programing (computers), Douglas-fir, forest management.

INTRODUCTION

Forest Management and Operations Research

Forest managers today are faced with increasingly complex planning situations brought on by such factors as the growing public demands on the forest resource, the transition from an old-growth to a young-growth forest resource, and the need to increase productivity from a shrinking forest land base. Many managers have found existing planning procedures inadequate.

Therefore, foresters are beginning to explore a branch of applied science known as operations research. Operations research is a general term referring to a wide range of methods with application to a large array of problems. In the study reported here, emphasis was placed upon the particular group of operations research methods commonly referred to as mathematical programing. Mathematical programing methods are used to solve management problems where it is useful to know the optimal or "best" solution and where managers must choose from among a large number of alternatives while being subject to a number of complicating and sometimes conflicting resource limitations and other restrictions.

In this paper, mathematical programing is used as the basis for a systematic framework for planning commercial thinning programs; however, the approach used should be of interest for planning other forest management activities. The intent of this report is to demonstrate a procedure--based upon an operations research technique--that will be of some value in designing more efficient systems for future forest management planning.

Study Objective

The objective of the study was to develop, demonstrate, and evaluate a systematic approach to planning annual commercial thinning operations that could be used to obtain optimal programs. "Optimal" was defined in terms of economic criteria. A further objective was to test the consequences (sensitivity analysis) of different management strategies and of changes in the planning situation (e.g., increases in stumpage prices).

Four major steps were required to accomplish the objectives.

1. A situation involving the planning of an annual commercial thinning program was described and modeled.
2. An economic criterion was selected, and a mathematical programing procedure was employed to select optimal programs and to conduct sensitivity analysis.
3. A case study area was used to demonstrate the optimizing approach.
4. The systematic planning approach was evaluated to determine its value in current planning efforts.

The evaluation in step 4 was designed to answer two specific questions:

1. How does the new planning procedure compare in performance and results with existing methods of planning?
2. What problems are involved with implementing the new approach?

The study was carried out in cooperation with the U.S. Bureau of Land Management (BLM), with its Tillamook Resource Area at Tillamook, Oregon, serving as a case study area.

PLANNING THINNING PROGRAMS

Basic Steps in Planning

A manager with the task of planning an annual thinning program has many things to consider. These considerations are presented below in the form of nine basic steps that would be involved in planning. It is suggested that foresters intuitively, if not consciously, follow these steps.

1. Determine objectives. Just what is to be accomplished by thinning? What objectives of the organization does thinning promote?
2. Select criterion. What standards shall represent our objectives? Can we use a dollar criterion such as present net worth or benefit cost, or is a standard based on volume yield more appropriate?
3. Identify thinning opportunities.[1] What stands or harvest units are available this year, and where are they located?
4. Evaluate thinning opportunities. What does each stand or unit contribute toward the objectives?
5. Identify constraints. What are the limitations on available funds and manpower? Must consideration be given to the number, size, and location of sales?
6. Choose a selection procedure. How will the choice among thinning opportunities be made? How will relevant constraints be accounted for?
7. Select program. Is the combination of thinning opportunities the best? If not, is it workable? Was proper account made of constraints?
8. Evaluate change in basic assumptions. What is the effect of changes in stumpage prices? discount rates? thinning practices?
9. Evaluate change in constraints. What is the effect of changes in funding? market locations? environmental requirements?

Program Selection Problems

Forest managers have developed various procedures to cope with the planning steps listed above. These procedures may be systematic and well documented up to the point where thinning opportunities are to be selected for inclusion in the program. At this point, however, choosing a workable program may become a difficult problem, especially as the number of constraints and opportunities increase.

In order to develop workable thinning plans, foresters generally resort to a combination of intuitive and explicit judgments, which in this study will be referred to as "rules of thumb." Examples[2] are:

1. Oldest stands are thinned first. For example, stands aged 70 would probably be thinned before stands aged 60.

[1] Thinning opportunities are defined as stands of young-growth Douglas-fir which could be thinned commercially. Opportunities may differ on the basis of age, size class, etc. Later, opportunities will be defined as specific thinning harvest units.

[2] These examples were provided by BLM foresters in Tillamook, Oregon, as representative of the considerations that guide the selection of stands for thinning. In the context of this study, rules of thumb should be considered as being undocumented judgments arising from the manager's assessment of economic, silvicultural, environmental, and other factors that bear upon the conduct of thinning operations.

2. Larger diameter classes are preferred over smaller classes. For example, a stand 60 years of age in size class 4 would be preferred to a stand 60 years of age in size class 3.
3. Stands on gentle slopes are preferred to stands on steeper slopes.
4. In general, stands gain in preference as the amount of road construction required to develop them decreases.
5. Stands where access rights are clearly established are preferred to stands where access rights are not clear or not yet established.
6. Stands gain in preference as their degree of basal area stocking increases.
7. Especially small thinning tracts (generally under 20 acres) tend to be avoided in favor of larger tracts.
8. Where property lines are important, stands with established corners are preferred to those with ill-defined corners.

Rules of thumb like these have served and continue to serve a useful purpose in management decisionmaking. However, it should be recognized that, basically, they are practical guidelines developed by foresters working on individual parts of the thinning program. Although the rules may be very sound for particular areas of the forest, they may not be applicable to the whole forest. Consequently, a planning procedure based solely upon rules of thumb may overlook important constraints, thinning opportunities, and questions.

OPERATIONS RESEARCH APPLIED TO THINNING PROGRAM PLANNING

Mathematical Programing— A Problem Solving Procedure

Mathematical programing is a problem solving procedure potentially applicable to solving many complex forest management problems in much less time and with much more accuracy than in the past.[3] Mathematical programing encompasses several specific methods designed for special problem situations. One of the better known of these methods is linear programing. Some others are dynamic programing, integer programing, and zero-one integer programing. Zero-one integer programing was used as the basis for the planning system developed for this study.

Although mathematical programing methods are based upon mathematical theory, some of the actual procedures, such as linear programing, require only a limited background in mathematics. In fact, small problems can be solved by hand, using some of these procedures. Most practical problems, however, are too large for hand calculation and require electronic computers to obtain accurate solutions in a reasonable time.

Although mathematical programing procedures differ in their compositions and functions, they are designed for problems that share certain important characteristics. Some of the major

[3] For readers further interested in mathematical programing approaches to forest management problems, a bibliography of such literature has been included.

elements that characterize mathematical programing problems are listed below.

1. The problem to be solved requires a "best" answer or, in mathematical programing terms, optimization. In order to achieve this, one management objective is specified for optimization (either maximization or minimization), a criterion is chosen to represent the objective, and all opportunities are evaluated in terms of this criterion.

   Examples of possible managerial objectives as they might apply to thinning program planning are:

   a. Maximize both present and future returns to the investment.
   b. Minimize annual costs of thinning sales preparation.
   c. Maximize average annual volume yields on the forest through thinning.

2. There are constraints on the operations and on the resources at the manager's disposal. For example:

   a. There are limitations on the level of expenditures permissible on thinning sale preparation.
   b. A ceiling is placed on the volume that can be harvested through thinning.
   c. Thinning sales must be scattered around the forest to avoid adverse environmental effects.

Constraints can take one of three forms:

   a. Those that set a maximum, e.g., no more than $75,000 can be spent on thinning sales preparation.
   b. Those that set a minimum, e.g., the thinning program will contain no fewer than 10 sales.
   c. Those that require specific levels, e.g., the thinning program will consist of exactly 10 sales.

3. The manager must have alternative means of attaining his objective. For example, a manager may have 100 distinguishable thinning opportunities from which he must choose 20 for thinning in the coming year. The mathematical program will select the optimal combination of these opportunities subject to the limitations imposed by specified constraints.

A Planning System Based on Harvest Units

In the planning approach developed for this study (fig. 1), a thinning opportunity is defined as a harvesting unit which would be purchased and thinned by one buyer. Managers would be required to determine the total number of units available in the planning year and then to select the best combination of thinning units for inclusion in the annual plan.

Using mathematical programs such as linear programing (LP) to select the best combination of thinning harvest units can involve solutions with fractional units.[4]

[4] Hall (1967, p. 470) has recognized the problem of obtaining solutions stated in fractions of units rather than in whole units:

> Treatment of fractional blocks as prescribed by LP solutions is often impractical, and simple rounding of acreages to whole blocks may invalidate the entire optimization for which the model was formulated. Efforts to schedule real blocks of land, rather than homogeneous but disconnected acres, require modification toward integer programming, where techniques are still developmental.

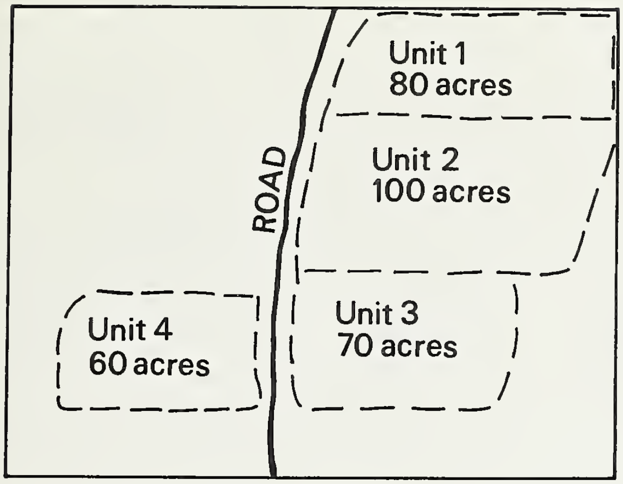

Figure 1.—The unit approach. Forest types eligible for thinning are divided into identifiable thinning units. Units are given identifying numbers. Program solutions will indicate which units should be thinned.

This means that the optimal solution may be composed of parts of logical harvesting units rather than whole units. Applied to the ground, these unit fractions may not be economical or even technically feasible as harvesting operations.

In order to eliminate problems of fractional units, a mathematical programing procedure known as zero-one integer programing was used. This procedure is specifically designed to handle problems requiring solutions in whole units. Basically a yes (one) or no (zero) decision is involved with respect to a particular unit's inclusion in the optimal solution. The zero-one integer programing procedure was the basis for the thinning planning approach hereafter referred to as the unit approach.

PLANNING COMMERCIAL THINNINGS ON THE BLM'S TILLAMOOK RESOURCE AREA

Application of the unit approach was carried out in cooperation with the U. S. Department of Interior, Bureau of Land Management, on its Tillamook Resource Area (fig. 2) located in Tillamook and Yamhill Counties and comprising approximately 50,000 acres of young-growth timber. Tillamook Resource Area is an administrative subunit of the BLM's Salem (Oregon) district which, in addition to the usual administrative functions, is managed for the purpose of field testing and evaluating the feasibility of various land management methods applicable to young-growth forests of the Douglas-fir region of western Oregon. In fiscal year 1969, commercial thinning was one of the major timber management activities on the Tillamook Resource Area, accounting for about 45 percent of a total timber harvest of 48 million board feet.

The purpose of this section will be to describe how the unit approach was applied to the problem of selecting an annual thinning program for the Tillamook Resource Area. The basic steps are described on page 2. The development of this section generally follows these steps beginning with the definition of the objective.

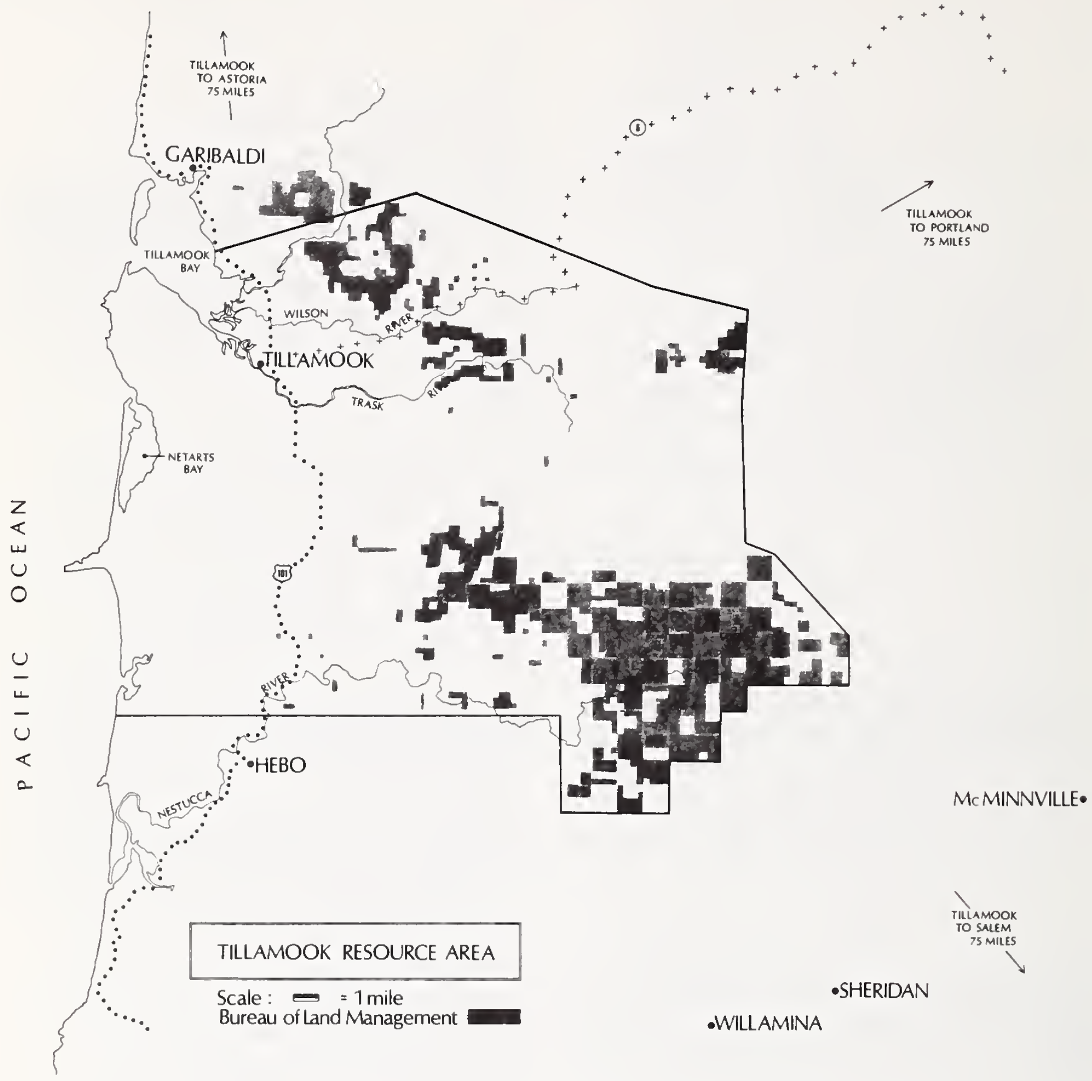

Figure 2.—Tillamook Resource Area.

Preparing the System

SELECTION OF OBJECTIVE AND CRITERION

Each thinning unit must be evaluated in quantifiable terms before it can be included in a mathematical programing format. This means that a criterion must be selected to represent the contribution of each thinning unit to management's objective. However, before a criterion can be selected the objective in thinning must be determined.

For the purposes of this study, it was assumed that the major objective of thinning would be to increase financial yields. This would be done primarily through increased volume and improved timber quality. The criterion chosen to represent the financial objective was the maximization of present net worth. Each unit was evaluated in terms of the contribution to present net worth expected from thinning the unit. The maximization of present net worth criterion was used to consider both present and future returns to thinning, and it was easily adaptable to the mathematical programing procedure used.

IDENTIFICATION OF ALTERNATIVES

A total of 50 units were identified as alternatives available for thinning. Table 1 presents a sample of five units to demonstrate the type of information used to identify and evaluate units.

The reader will note that table 1 includes information on thinnable type acreage as well as unit acreage. Thinnable types were considered to be coniferous stands 30 to 70 years of age with over 70-percent-normal basal area stocking. It was necessary to account for types lying within each unit for purposes of evaluation. Each type was evaluated separately and weighted by acreage to obtain unit evaluations.

Forest type maps were used to identify thinnable types on the basis of age and size class, and topographic maps were used to distinguish alternatives occurring on tracts that could be thinned by tractor yarding methods and stands on steeper (over 45 percent) ground that would require cable methods of yarding. The age classes represented were 30, 40, 50, 60, and 70 years. The three size classes represented were size classes 2 (timber 5- to 11-inch d.b.h.), 3 (timber 11- to 21-inch d.b.h.), and 4 (timber 21 inches and larger d.b.h.).

Units were specified by foresters on the Tillamook Resource Area. The foresters indicated what they thought were the best number and layout of thinning units in accessible areas and provided information concerning inaccessible areas, areas with excessive slopes, roadbuilding requirements, and appropriate harvesting methods.

EVALUATION OF ALTERNATIVES

In order to determine the returns from thinning a particular unit, the returns from thinning each thinnable type within the unit had to be calculated. The returns from each thinnable type were then weighted by their acreage to obtain total returns for the unit.

Returns for each thinnable type were stated in terms of per-acre present net worth and were derived from three steps: (1) calculation of volumes, (2) calculation of stumpage values, and (3) calculation of present net worths.

Table 1.--*Five examples of the format and information used to identify and evaluate units for the unit approach*

Unit number	Thinnable types			Acres
	Age class	Size class 1/	Slope 2/	
2	60	3	M	74
				74
4	30	2	M	2
	70	3	M	28
	70	3	S	51
				81
6	70	3	S	84
				84
11	30	2	M	2
	70	3	M	97
	70	3	S	28
				127
48	60	4	M	43
	40	3	M	6
	60	3	M	30
				79

1/ Size class 2 represents timber 5- to 11-inch d.b.h., size class 3 represents timber 11- to 21-inch d.b.h., and size class 4 represents timber 21 inches and larger d.b.h.

2/ S represents slopes over 45 percent requiring cable methods, and M represents slopes less than 45 percent on which tractors can be used.

1. *Calculation of volumes.*--Three categories of volume data were required for each thinnable type. These data were the volume to be thinned, the volume expected at final harvest in a thinned stand, and the volume expected at final harvest in an unthinned stand. The volume data generated for these categories were on a per-acre basis and were based upon data and assumptions provided by the Bureau of Land Management.

2. *Calculation of stumpage values.*--Stumpage values had to be derived for current thinning operations and for final harvest operations in both unthinned and previously thinned stands. These had to be calculated for each thinnable type on a per-thousand-board-foot basis.

The standard U. S. Bureau of Land Management (1967) procedure for appraising timber sales was used to obtain the stumpage values used in this study.

Constant prices and costs were assumed for the projection of future stumpage values of both thinned and unthinned final harvest volumes. It was also assumed that price and cost advantages would accrue to final harvest yields from thinned stands as opposed to unthinned stands, because of the expectation that previously thinned stands would be cheaper to harvest and would yield, on the average, larger timber of better quality.

3. *Calculation of present net worths.*-- For each thinnable type a per-acre present net worth value was derived. Per-acre values were calculated by multiplying the volumes per acre (from step 1) obtained from thinning and at final harvest by the appropriate stumpage values (from step 2). The final harvest values were discounted to the present. In order to obtain net values, administrative costs of conducting thinning programs and the subsequent final harvests were deducted. The basic calculation for each thinnable type consists of subtracting the discounted final harvest value if no thinning is done from the sum of the value of thinning in the present year and the discounted final harvest value in a thinned stand (see footnote 3, table 2).

The results of the calculation of present net worths are a per-acre value assigned to each type. These are shown in table 2. Table 3 shows the thinning unit values which are determined from the values in table 2 weighted by the thinnable type acreages occurring within each unit.

FORMULATION OF CONSTRAINTS

Constraints are limits upon what the manager can do in seeking his objective. Constraints can take the form of budget limitations, manpower availability, allowable cuts, physical limitations, and operational requirements.

Mathematical programing procedures require two kinds of information for each constraint. First, a constraint requirement must be set. This is usually stated as some minimum or maximum level; e.g., no more than $75,000 shall be spent on the thinning program or no less than 10 million board feet shall be harvested from area A. Second, each thinning alternative must be evaluated in terms of these requirements. In terms of the examples above, thinning unit X will require some portion of the thinning budget and will contribute a portion of the volume needed.

Six categories of constraints were identified and used in planning the Tillamook thinning program. An example of each category is given below.

1. *Controls on how much volume could be thinned.* No more than 20,700,000 board feet could be thinned in fiscal 1969.
2. *Controls on how much money could be spent.* Approximately $73,000 was provided for carrying out a thinning program. Expenditures could not exceed this budget.
3. *Controls on where volume could be thinned.* At least 10 million board feet had to be thinned in the northern part of the Tillamook Resource Area.
4. *Controls on which units could be chosen.* Because of road location requirements, units 44 and 45 could not be sold in the same year.
5. *Controls on the number of units.* No more than 12 thinning units could be sold in fiscal 1969.
6. *Controls on the size of units.* At least three sales (units) had to be less than 1 million board feet.

Table 2.--*The contribution to present net worth of thinning by forest type*

Age class	Size class[1/]	Topography class[2/]	Contribution to present net worth[3/]
			Dollars per acre
30	2	M	40.13
40	2	M	189.32
30	3	M	160.46
40	3	M	330.84
50	3	M	526.45
60	3	M	675.87
70	3	M	712.67
60	4	M	804.91
70	4	M	834.22
30	2	S	21.86
40	2	S	152.22
30	3	S	128.48
40	3	S	278.77
50	3	S	453.86
60	3	S	597.25
70	3	S	644.14
60	4	S	705.61
70	4	S	757.90

1/ Size class 2 represents timber 5- to 11-inch d.b.h., size class 3 represents timber 11- to 21-inch d.b.h., and size class 4 represents timber 21 inches and larger d.b.h.

2/ S represents slopes over 45 percent requiring cable methods, and M represents slopes less than 45 percent on which tractors can be used.

3/ Contribution to present net worth (*PNW*) is made up of three values: value of thinning in the present year (*RT*), present value of final harvest value if thinning takes place in the type (*RHT*), and present value of final harvest value if no thinning is done (*RHW*). The last column is derived from *PNW* = *RT* + *RHT* - *RHW*.

Table 3.--*Present net worth in dollars for units available for thinning in fiscal year 1969*[1]

Thinning unit number	*PNWT*	Thinning unit number	*PNWT*	Thinning unit number	*PNWT*
1	36,526	18	198,836	35	46,935
2	49,638	19	32,070	36	32,535
3	29,781	20	44,647	37	31,030
4	52,026	21	128,292	38	166,262
5	45,282	22	99,421	39	35,450
6	53,504	23	25,384	40	80,769
7	61,231	24	42,115	41	53,340
8	109,907	25	121,155	42	36,082
9	89,382	26	3,399	43	57,900
10	30,181	27	55,839	44	82,156
11	87,245	28	116,627	45	66,902
12	78,585	29	31,558	46	41,343
13	81,197	30	49,995	47	56,825
14	53,529	31	82,996	48	58,546
15	54,719	32	36,399	49	23,081
16	35,230	33	50,642	50	17,109
17	142,525	34	17,705		

[1] The following formula was used to determine unit present net worth from thinning (*PNWT*):

$$\text{Unit } PNWT = \sum_{i=1}^{n} (\text{acres of type } i \times PNWT_i)$$

where n = number of thinnable types in a unit.

Operating the System

SELECTING OPTIMAL PROGRAMS

In figure 3, the steps involved in preparing the system and in selecting the optimal program are diagramed. This diagram may be useful in interpreting table 4, which shows the results of using mathematical programing to select an optimal thinning program based on harvesting units.[5] The optimal solution was selected from a planning problem involving 50 units and 13 constraints.

[5] The computer program used for the solution of unit approach problems was obtained from the Rand Corporation. The program (Geoffrion and Nelson 1968) is a 0-1 integer linear programing code, referred to as RIP30C. The code will handle up to 90 variables and 50 constraints. Readers interested in the background of this code should refer to Balas' (1965) original development of the 0-1 algorithm, Petersen's (1967) experience in testing variants of Balas' algorithm, and Geoffrion's (1967, 1969) work which led to the development of RIP30C. The 0-1 integer program was run on a CDC 6400.

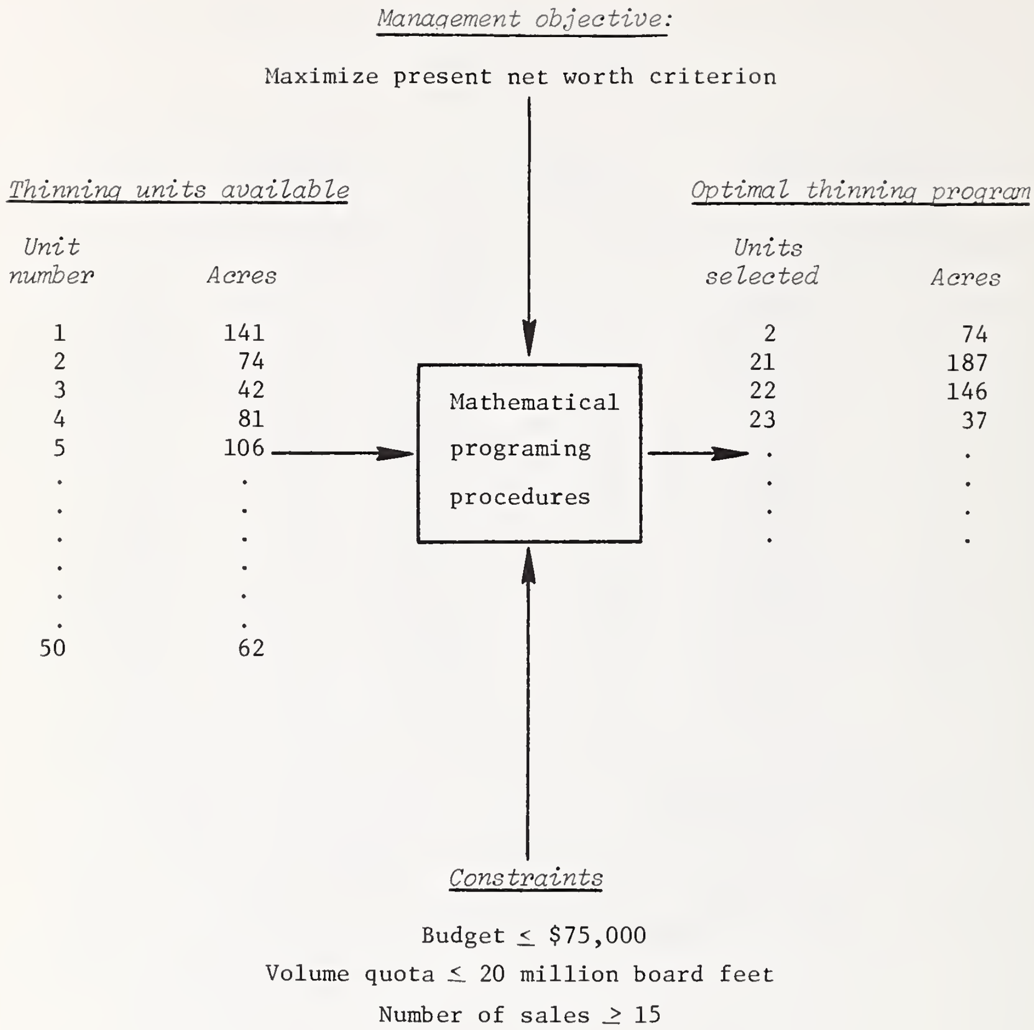

Figure 3.—Example of major elements of a unit approach framework.

Table 4, along with figure 3, gives a good overall view of the unit approach as discussed to this point. Elements of both the selection process and the preparation process are shown in the table. Information concerning the solution to the optimal program is given in column 1 where the units selected are shown and in the total row of column 2 where the total value of the program is shown. The numbers in columns 2 and 4 through 6 are inputs to the system. They are developed in the preparation phase, as are the constraint requirements shown in the bottom row.

Table 4.--*Results of selecting the optimal program of thinnings*

Unit number	Selected unit		Constraint		
	Present net worth from thinning	Size	Volume thinned	Engineering administrative costs	Sales layout administrative costs
(1)	(2)	(3)	(4)	(5)	(6)
	Dollars	*Acres*	*Thousand board feet*	*Dollars*	*Dollars*
2	49,638	74	846.9	0	3,176
21	128,292	187	2,140.2	396	8,026
22	99,421	146	1,671.0	342	6,266
23	25,384	37	423.5	69	1,588
27	55,839	82	938.5	354	3,519
28	116,627	192	2,197.5	450	8,240
29	31,558	46	526.5	99	1,974
30	49,995	83	949.9	114	3,562
31	82,996	150	1,627.1	312	6,275
32	36,399	52	621.9	0	2,332
34	17,705	26	297.6	84	1,116
37	31,030	40	519.5	84	1,786
38	166,262	253	2,902.5	285	11,156
41	53,340	71	904.7	0	3,294
43	57,900	78	988.0	30	3,620
47	56,825	71	956.7	240	3,202
48	58,546	79	962.3	30	3,367
Total	1,117,757	1,667	19,474.3	2,889	72,499
Constraint requirements	--	--	20,700.0	3,100	73,000

Notice that the numbers in the total row do not exceed the constraint requirements. The mathematical programing procedure assures that stated constraint requirements are not violated.

EVALUATING CHANGES IN THE PLAN

Managers and planners can learn much about the important factors influencing the selection of a thinning program by using a process known as sensitivity analysis. In general, sensitivity analysis involves determining the degree of change in the optimal value of a program resulting from a change in program inputs; e.g., changes in constraint requirements and evaluation assumptions. Sensitivity analysis can also examine changes in program composition; i.e., changes in the number and location of harvesting units. With information provided by sensitivity analysis, managers may learn which inputs have the greatest influence on the organization's objectives.

Changing Constraint Requirements

Suppose the forest manager is interested in the effects of changing some of the constraint requirements shown in the bottom row of table 4. In rule-of-thumb planning, the manager can speculate about what might happen if the requirements were changed, but normally he doesn't have the time or resources to recompute the whole thinning program in order to find out exactly what would happen. Using a mathematical programing procedure, the manager can obtain a recomputed program in much less time than would be possible with hand calculations. As with the original solution, the recomputed solution would also be optimal, only now based on the changed constraint requirements. An illustration taken from the case study will serve to demonstrate this procedure.

Suppose the forest manager is concerned about the figures shown in the total and constraint requirements rows of column 4 in table 4. He observes that if the optimal solution in table 4 is followed, only 19,474,000 board feet will be thinned. This is well below the maximum allowed, which is 20,700,000 board feet. He may not be satisfied with this optimal program, feeling that volume thinned should be substantially closer to the maximum allowable. What can he do? He can examine each constraint requirement to determine which are limiting; i.e., which constraints prevented additional units from being taken and thus prevented the total thinning volume from being higher.

Table 4 shows that total sales layout costs are only $500 less than the constraint requirement of $73,000, thus indicating that this constraint may be the one most limiting the optimal solution. If insufficient sales layout funds are responsible for failure to attain the 20,700,000 board-foot level, how much additional funding is needed? In order to determine this, the sales layout cost requirement of $73,000 can be dropped, i.e., there will be no limits on what can be spent for sales layout costs. The program is run again and a new optimal solution is obtained. The results are shown in table 5.

This analysis shows that insufficient funding was responsible for the failure to obtain a harvest of 20,700,000 board feet, and that almost $6,000 in additional funding would be required to obtain this harvest level. The additional funding would raise the total program value by over $45,000 and would decrease engineering (road layout and design) costs slightly. Engineering costs decreased because three units shown in table 4 were replaced by units requiring less engineering work.

Table 5.--*Comparison of two optimal thinning programs with differences based on availability of funds for sales layout*

Sales layout funding level	Volume thinned	Sales layout costs	Engineering costs	Present net worth value of program	Number of units
	Thousand board feet	*Dollars*			
(A) $73,000 limit	19,474	72,499	2,889	1,117,757	17
(B) No limit	20,677	78,376	2,766	1,162,839	19
Difference (B - A)	+1,203	+5,877	-123	+45,082	+2

The preceding example involved only one question and one test. Other questions could have been asked and tested; e.g., What would be the result of a reduction in funding? What would be the effect on program value if harvest units had to be more widely dispersed because of esthetic or environmental considerations?

There is great potential in these procedures for obtaining quick answers to questions that often come up in the course of planning forest management programs. Mathematical programing procedures may also encourage managers to ask questions that have been ignored or overlooked before, simply because there was no easy way to obtain answers.

Changing Assumptions

Obtaining present net worth values for thinning harvest units requires a number of assumptions about stumpage prices, the results of thinning, and management practices. Some of the assumptions in this study were:

1. Stumpage prices used to evaluate thinning units reflected price and cost conditions existing during the spring of 1968.
2. Final harvest cutting age was assumed to be 80 years.
3. Because of anticipated timber quality improvements and lowered logging costs in thinned as opposed to unthinned stands at the time of final harvest, a $10-$12 stumpage price advantage was assumed for thinned stands.
4. Thinning would remove from 20 to 30 percent of the basal area of the stand, depending on stand age (youngest stands were cut at 30 percent, oldest at 20 percent).
5. A discount rate of 4-5/8 percent was used, reflecting the recommended rate for this type of government investment at the time.

Each of these assumptions requires the specification of numbers. What happens if the numbers are wrong or if they change? How will program values and composition be affected by errors or changes; i.e., how sensitive are the results of the program to variations in the assumptions? Mathematical programing can be used in helping to determine just how crucial some of these assumptions are.

For example, what would be the effect on program value and composition if 1970 stumpage prices and discount rates were used in place of 1968 values? This question was tested using the procedures developed in the unit approach. The results showed a 25-percent decrease in program value, but no change in the units making up the program. Tests involving the other assumptions were also conducted. In some instances, changes were dramatic in both program value and composition, indicating that these assumptions might be critical to the success of the planning effort. Information developed from these sensitivity tests will show the manager where the greatest care must be taken in formulation of assumptions and collection of data.

Before managers can use mathematical programing to test changes in assumptions, an additional computation is necessary--new present net worth unit values are developed each time a change in assumptions takes place. This can be a tedious process; thus it is desirable to computerize these procedures if possible. A computer program was developed in this study for use in generating new present net worth values for each unit. This program can be considered an integral part of the unit approach, and it plays a vital role in obtaining rapid answers to questions involving assumptions.

EVALUATING THE SYSTEM

Effectiveness of the Unit Approach

This study was designed to develop and test a new planning approach that could be useful to forest managers working with complex planning problems. Usefulness was interpreted as the effectiveness of the unit approach in (1) providing information for the basic planning steps shown on page 2, (2) organizing information in a systematic manner that accounts for management's objectives, alternatives, and constraints, and (3) documenting information so that there is a record of all important information of the plan.

The effectiveness of the unit approach was compared both with existing planning procedures, as found on the Tillamook Resource Area, and with systematic planning procedures that would incorporate all the steps of the unit approach except those using mathematical programing. The comparisons are summarized in table 6.

EFFECTIVENESS IN PREPARING THE SYSTEM

Table 6 shows that the unit approach was more effective than existing methods in documenting information in a systematic form. However, the table also shows that existing planning procedures could be modified to provide the same kind of information. In other words, mathematical programing procedures are not necessary to obtain documented systematic information for the first four steps of table 6. The same information could be obtained by management's careful consideration of objectives, alternatives, and constraints without any intention of using a mathematical program to obtain an optimal solution. However, although mathematical programing procedures are not necessary for collecting documented planning information, their use does provide a ready-made systematic framework for organizing and interpreting information often lacking in planning systems based on rules of thumb. Within this framework, objectives must be defined first. After objectives are defined and criteria specified, the kinds of information required are relatively

Table 6.--*Comparative effectiveness*[1] *of three approaches to planning thinning programs in relation to the major planning steps*

Major steps in planning thinning programs	Existing planning procedures	Systematic planning procedures not using mathematical programing	Unit approach
Specifying objectives and criteria	x	xxx	xxx
Identifying and locating thinning units	xx	xxx	xxx
Evaluation of thinning units in terms of criterion	x	xxx	xxx
Consideration of all relevant constraints	x	xxx	xxx
Selection of optimal program--Is it the best one?	x	x	xxx
Evaluate consequences of changing constraints and assumptions (sensitivity analysis)	x	x	xxx

[1] Effectiveness is indicated by:

xxx - Approach provides *systematic, documented* information that essentially fulfills management's needs for preparing a thinning plan.

xx - Approach provides *systematic, documented* information but important elements may be left out.

x - Approach provides information mainly in an intuitive way, or not at all. Although management gets some of the needed information, there is no documentation nor way to verify results.

easy to identify and document. Without such a framework, important alternatives and constraints may be overlooked. Also, documentation may be incomplete and poorly organized, thus reducing the effectiveness of available information either as support for the current plan or as a basis for future planning.

The cost of adopting more systematic planning methods is probably their major disadvantage. In the study reported here, approximately 2 man-months were required to put together the information included in the first four steps of table 6. This study involved only the planning of thinning operations on a 50,000-acre tract of young-growth timber. Planning of programs involving larger areas and more activities would obviously require more manpower. On the brighter side, once the system is set up, a substantial portion of the cost would not need to be repeated. The major cost in subsequent years would be in updating the system.

EFFECTIVENESS IN SELECTING THINNING PROGRAMS

Mathematical programing was used to select optimal thinning programs; i.e., programs which could not be improved upon in terms of the original objective, alternatives, and constraints. If the program could be improved upon, then somewhere in the preparation stage, objectives, alternatives, and constraints were not completely or correctly specified.

If managers are provided with optimal programs, there are at least two ways these programs could be used. The optimal program could be adopted directly as the plan or it could be used as a standard against which programs developed by rules of thumb could be checked. In the latter approach, if rule-of-thumb program values closely approached optimal standard values, managers might be content to leave the program unchanged. If, however, large discrepancies appeared, managers would probably want to know the reason.

Comparing results of using the rule-of-thumb selection method with results of using the mathematical programing method showed that the mathematical programing planning procedure produced thinning programs that ranged from 1 to 7 percent higher in value (present net worth) than programs based on existing rule-of-thumb procedures, depending on the assumptions used. The 7-percent improvement was obtained on a program valued at nearly $1,200,000 (based on rule of thumb) and amounted to $82,000.

Improvements were not dramatic, but this may have been due to the size and characteristics of the study area. The Tillamook Resource Area has a relatively small area compared with many management districts, and the forest is relatively uniform in age. These factors may have resulted in a smaller number of alternatives and constraints and thus a simpler problem. Larger areas with greater variability in timber types would probably show a wider range of alternatives and constraints and thus more dramatic improvements with mathematical programing.

The major costs of obtaining an optimal program involve preparing the inputs. This was discussed in the preceding section. Once the objective, criterion, alternatives, and constraints are all specified and evaluated, the additional cost of obtaining an optimal solution is relatively small. In this study, optimal solutions were obtained for less than $5 each in computer time and clerical help (mainly keypunching).

EFFECTIVENESS IN TESTING CONSTRAINTS AND ASSUMPTIONS

Managers in charge of planning thinning programs must often proceed with one basic set of assumptions that represents a best guess. Although managers might have questions concerning the outcomes of alternative assumptions, they normally have no mechanism by which to get answers at reasonable cost. Lack of answers can lead to embarrassment if overcutting results, certain market areas are overlooked, or funds or manpower fall far short of needs. With the systematic approach and speed of analysis possible with mathematical programing, many of these problems may be avoided by obtaining answers to anticipated problems well in advance of their occurrence. For example, if a decrease in program funding is anticipated, the effect of this on the value and composition of the program can be ascertained and plans can be made to minimize the impact.

Evaluating constraint changes usually involves no more than changing a few input cards and then obtaining a new optimal solution. The cost of this process was the cost of optimal solution--no more than $5.

Evaluating changes in assumptions required a special computer program to generate new present net worth values with each new assumption. The cost of generating each new set of values was no more than $3. Add to this the $5 cost of

an optimal program, and the total cost of evaluating a change in assumptions was no more than $8.

Implementing the Unit Approach

The unit approach was effective in executing the planning steps assigned to it in the case study. Yet, this study was just one trial. Much remains to be done before the unit approach or any other operations research system becomes an integral part of the forest planning process.

Probably the major difficulty in implementing systems based on operations research is the fact that most forest managers are unfamiliar with the principles and techniques involved. This means that before progress can be made in applying these systems to practical planning problems, planners and managers will have to receive some training in operations research and specialists will have to be consulted or added to planning staffs. This, of course, will involve commitments of time and money, often well in advance of any benefits.

Further implementation difficulties can be expected in obtaining solutions for large-scale planning situations. For example, the computer program used in this study could handle up to 90 units and 50 constraints. This was perfectly adequate for a case study involving 50 units and no more than 20 constraints. However, if the unit approach had been applied to a larger planning area, or if long-range planning had been involved instead of an annual plan, the limits of the computer program could have been exceeded. In such a situation, a program capable of handling larger scale problems would have to be found. Larger scale problems also can be expected to add to the costs of solution; however, the added complexity of such problems would probably increase the value of having an optimal solution.

CONCLUSIONS

This study demonstrated that a workable planning system (the unit approach) could be developed from operations research techniques and could be applied to planning thinning operations. The principles of mathematical programming were used as a systematic framework to guide the organization and documentation of information, and the optimization procedures were used to obtain optimal programs under varying assumptions and constraint conditions.

Although program values were not dramatically improved, use of the unit approach did provide (1) a systematic overview of the planning situation, (2) guidelines for organizing information, (3) more thorough documentation, (4) an optimal program which could serve as a standard for rule-of-thumb programs or be used as the actual program, and (5) the means of answering many different planning questions.

Costs were highest in preparing inputs to the unit approach. The major effort in preparation was in organizing and documenting information already at hand into a form that could be used in the optimization program. The costs of obtaining optimal programs were relatively low compared with preparation costs.

This study represents an effort to bring systems analysis and the techniques of operations research to a phase of the management of young-growth Douglas-fir. The ultimate value of these methods to forest resource planners is hard to assess, but the potential value of these methods as aids to management seems too great to ignore. With managers facing increasing

and conflicting demands on the forest resources in combination with the need for greater productivity and efficiency, now seems an opportune time to begin wider experimentation and even implementation of these methods.

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